TECHNOLOGIES FOR ADAPTATION TO CLIMATE CHANGE

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Further information contact:
Climate Change Secretariat (UNFCCC)
Martin-Luther-King Str. 8
53175 Bonn, Germany
T: +49 228 815 1000
F: +49 228 815 1999
secretariat@unfccc.int
www.unfccc.int

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Preface

As past and ongoing greenhouse gas emissions take their inevitable toll on the climate, adaptation, which refers to finding and implementing sound ways of adjusting to the adverse effects of climate change, is becoming an urgent priority along with mitigation of climate change. While mitigation actions are already being implemented, work on adaptation focused so far on establishing important adaptation principles. This work has been largely completed and the path has been cleared for real adaptation-related action on the ground.

Most methods of adaptation involve some form of technology – which in the broadest sense includes not just materials or equipment but also diverse forms of knowledge. Unlike those for mitigation, the forms of technology for adaptation are often fairly familiar. Indeed, many have been tried and tested over generations – coping with floods, for example, by building houses on stilts or by cultivating floating vegetable plots. But other forms are much more recent, involving advanced materials science, perhaps, or remote satellite sensing.

For all these technologies, one of the main challenges is to ensure that they serve those in greatest need – the developing countries and most vulnerable communities, particularly those who live and work in close contact with the natural environment and who stand to lose most, and perhaps even their livelihoods, when ecological resources are under threat. And, of course, methods of adaptation ultimately need to be boosted by political and social action.

The United Nations Framework Convention on Climate Change secretariat and the Expert Group on Technology Transfer carried out an extensive review of adaptation technologies and assessed their possibilities in five sectors: coastal zones, water resources, agriculture, public health and infrastructure. The review is published as a technical paper: *Application of environmentally sound technologies for adaptation to climate change* (FCCC/TP/2006/2), and can be found on the UNFCCC website (www.unfccc.int).

This brochure summarizes and illustrates conclusions of the review and serves as a brief introduction to the principles and methods of adaptation and the practical steps that can be taken to put them into practice, while the above-mentioned technical paper provides the detail.

In many ways, this publication provides an overview of the old and the new, showing that humankind has always used existing knowledge to adapt to changing environments and that new adaptation technologies and methods are available or are being developed. It thus reminds us of what is possible. Guided by the established adaptation principles, we are well on the way towards implementing solid, sound and practical adaptation actions at ground level.

Yvo de Boer
Executive Secretary
United Nations Framework Convention on Climate Change
November 2006

The threat of climate change

Human societies have long been subject to disruption by climate change. In the past, most of these variations have reflected natural phenomena, from fluctuations in levels of solar radiation to periodic eruptions of volcanoes. But in future most climate change is likely to result from human actions, and in particular from the burning of fossil fuels and changes in global patterns of land use. These and other developments have been increasing the atmospheric concentrations of certain gases – chiefly carbon dioxide, methane and nitrous oxide – called greenhouse gases (GHGs) because, accumulating in the upper atmosphere, they act like the roof of a greenhouse, trapping long-wave radiation and thus raising temperatures and provoking other forms of climatic disruption.

This process has been accelerating. Since the beginning of the industrial revolution the atmospheric concentration of carbon dioxide has increased exponentially from about 280 parts per million (ppm) in 1800 to about 380 ppm today and there have been similar increases for methane and nitrous oxide. The rate at which the levels will rise in the future is difficult to estimate; this will depend on a complex interplay of many factors, including rates of population expansion, economic growth and patterns of consumption. The Intergovernmental Panel on Climate Change (IPCC) has projected that by 2100 atmospheric concentrations of carbon dioxide could have reached between 540 ppm and 970 ppm and that, as a result, global surface temperature could rise by between 1.4°C and 5.8°C.

However, the effects will be not be uniform. For one thing, the changes will differ from one location to another; global warming will, for example, be greater at higher latitudes than in the tropics. And there could also be different weather consequences; while some regions will have more intense rainfall, others will have more prolonged dry periods and a number of regions will experience both. The social consequences too will vary, depending, for example, on levels of development; in South Asia extra tropical storms could kill tens of thousands of people, while in the United States they might kill fewer people but lead to billions of dollars worth of damage. And even within the same society there will be differential social impacts; for young people greater heat stress may simply be a minor inconvenience, while for the elderly it can be fatal. But across the world and in every country those most at risk will typically be the poorest, and in developing countries these will often be those who depend most for their survival on a healthy natural environment, such as ethnic tribes or nomadic groups, fishing communities, smallholders and livestock herders.

The impact will vary according to a society's capacity to prepare for these disruptions – and to respond. When faced with a sea level rise, countries such as those around the North Sea, for example, have advanced technological and institutional systems that enable them to take appropriate action, while small island States in the South Pacific, lacking the necessary resources, will have fewer options.

The adaptation imperative

These threats have aroused widespread international concern and demands for action. The most basic requirement has been to investigate the extent of the problem and since the 1990s the IPCC has issued a series of reports detailing the extent of greenhouse gas emissions and indicating potential consequences by presenting a range of scenarios.

On the basis of this information, governments came together to draft the United Nations Framework Convention on Climate Change, which came into force in 1994. The Convention envisaged two main strategies to address global warming: mitigation and adaptation. Mitigation involves finding ways to slow the emissions of GHGs or to store them, or to absorb them in forests or other carbon sinks. Adaptation, on the other hand, involves coping with climatic change – taking measures to reduce the negative effects, or exploit the positive ones, by making appropriate adjustments.

Until recently, policy makers concentrated on mitigation, partly because of worries that highlighting adaptation options might reduce the urgency for mitigation. But there was also an implied division of responsibility. For while mitigation clearly demanded positive action by governments, adaptation was a task that might perhaps be left to others, allowing adjustments to occur automatically through the "invisible hands" of natural selection and market forces.

It is now clear, however, that mitigation and adaptation are not alternatives; both need to be pursued actively and in parallel. Mitigation is essential and adaptation is inevitable. Mitigation is essential because, without firm action now, future generations could be confronted with climate change on a scale so overwhelming that adaptation might no longer be feasible. But mitigation will not be enough on its own. Even if today's efforts to reduce emissions are successful some adaptation will be inevitable because climate change occurs only after a long time-lag. Current global warming is the consequence of emissions decades ago, and the process will continue; even the most rigorous efforts at mitigation today will be unable to prevent climate changes in future.

Moreover, it is also evident that governments cannot leave adaptation entirely to social or market forces. To some extent, adjustment decisions will indeed take place in a dispersed and fairly autonomous fashion, at the household or individual level: farmers, for example, may react to changes in temperature by growing different crops, or homeowners or businesses may respond to hotter weather by buying air conditioning systems. But other essential forms of adaptation will demand that institutions, both public and private, plan their strategies and take action in advance. Coastal authorities, for example, will aim to address sea level rises by building dykes, and housing authorities that want future constructions to withstand climate changes will need to introduce appropriate building codes. This distinction between reactive and anticipatory adaptation is illustrated in figure 1. Clearly, natural systems can only react but human systems, both public and private, can and should anticipate and plan ahead.

Figure 1. Types of adaptation to climate change

		Anticipatory	Reactive
Natural Systems			• Longer or shorter growing seasons • Migration of wetlands • Changes in ecosystems
Human Systems	Private	• Changing architecture of buildings • Buying hazard insurance • Devising new consumer products	• Moving home • Changing insurance premiums • Buying air conditioning systems
	Public	• Installing early warning systems • Establishing new building codes • Constructing dykes	• Offering compensation or subsidies • Enforcing building codes • Beach nourishment

Technologies for adaptation

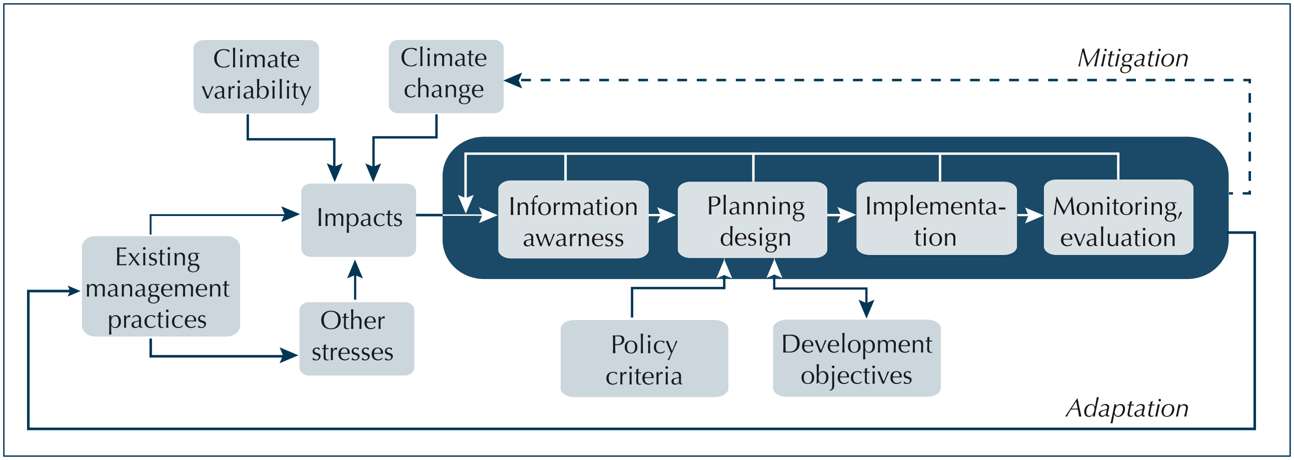
In many cases people will adapt to climate change simply by changing their behaviour – by moving to a different location say, or by changing their occupation. But often they will employ different forms of technology, whether "hard" forms, such as new irrigation systems or drought-resistant seeds, or "soft" technologies, such as insurance schemes or crop rotation patterns. Or they could use a combination of hard and soft, as with early warning systems that combine hard measuring devices with soft knowledge and skills that can raise awareness and stimulate appropriate action.

Many of these technologies are already available and widely used. The global climate system has always confronted human societies with extreme weather events and in many respects future climate change will simply exacerbate these events, altering their scale, duration or intensity. Thus it should be possible to adapt to some extent by modifying or extending existing technologies. These may date back hundreds of years. Local communities have, for example, used traditional technologies to cope with regular flooding by building houses on stilts, and many communities continue to do so, even if they use more modern materials such as concrete pillars or corrugated iron roofs. Other technologies might be considered "modern", dating from the industrial revolution in the late eighteenth century. Farmers have taken advantage of technological advances to cope better with arid environments, introducing new crop hybrids and making better use of scarce water, as with systems of drip irrigation.

Nowadays human societies can also take advantage of "high" technologies such as earth observation systems that can provide more accurate weather forecasts, or crops that are based on genetically modified organisms. Finally too, people can look towards an horizon of future technologies yet to be invented or developed – which might include crops that need little or no water, or a malaria vaccine.

Whatever the level of technology, its application is likely to be an iterative process rather than a one-off activity. This is illustrated in figure 2 which shows planned adaptation as an idealized four-stage sequence. First, those responsible collect and interpret the necessary information. Second, they design an appropriate response that is not only technically feasible but also is consistent with the country's development objectives, as well as some key policy criteria – the technologies will need to be cost-effective, environmentally sustainable, culturally compatible and socially acceptable. Third, those responsible move to implementation, which in addition to installing systems means ensuring that these are actively supported by effective institutions, formal and informal, from national organizations to village communities. Fourth, they must continually monitor and evaluate these technologies to allow for adjustments, course corrections, and further innovation and feedback. Although many of these technologies will already be available and in place, they often need further investment to make them more effective – using different materials, for example, or modified designs. And in addition there will be technologies embodied in know-how or materials or equipment that having been employed in one location or country could usefully be replicated elsewhere.

Figure 2. Iterative steps in planned adaptation to climate change



Thus far, such technology transfers have mostly been for purposes of mitigation, and have primarily been for the energy sector and have typically involved transferring ideas or equipment from developed to developing countries. There may thus be a temptation to envisage transfers for adaptation following the same pattern. It is important to emphasize, however, that technologies for adaptation differ from those for mitigation in a number of important respects. Unlike mitigation, which is a relatively new task, adaptation is generally the continuation of an ongoing process for which many of the technologies are already being applied even in some of the least developed countries. Moreover, adaptation, rather than being concentrated in one sector, such as energy, will essentially be ubiquitous, dispersed across all socio-economic sectors – including water, health, agriculture and infrastructure – each of which presents its own challenges, and will involve myriad stakeholders in different if overlapping groups. In many respects, compared with mitigation, adaptation is thus far more diverse and complex.

Adaptation measures are also likely to be less capital intensive and more amenable to small-scale interventions. They should therefore be more flexible and adaptable to local circumstances which means that in addition to being socially and legally acceptable they can be made reasonably cost-effective. Nevertheless, as with any form of technology there is always the risk that adaptation measures will be more accessible to wealthier communities. Policymakers thus need to ensure that new forms of adaptation do not heighten inequality but rather contribute to a reduction in poverty.

Coastal zones

A substantial proportion of the world's population lives at the interface of land, sea and air in the world's coastal zones. Here people can exploit many opportunities for investment and production but also find themselves exposed to a range of natural hazards, from storms and cyclones to widespread flooding and coastal erosion.

Climate change will make some coastal zones even more hazardous. The most consistent effect will be to raise sea levels. It is difficult to predict the likely rise in different regions but estimates have been made for the global mean sea level: between 1990 and 2100 this is projected to rise by between 9 and 88 centimetres. Climate change also threatens coastal zones with an increase in the frequency and intensity of extreme events such as high winds and tropical cyclones. However, these are extremely difficult to model and it is even harder to make predictions for different regions.

Moreover, for many coastal cities the risks will be compounded by a fall in land levels. As cities have expanded, urban communities have been extracting more and more groundwater and as a result in some places the soil has consolidated and the land has subsided. In the late 1980s the land around Tianjin in China, for example, was sinking at around 5 centimetres per year, and in some locations by 11 centimetres per year. For cities located in large deltas, another factor leading to subsidence is loading by sediment deposition.

In coastal zones these changes could have a number of effects, including more frequent flooding, coastal erosion and the intrusion of salt into groundwater. Six of the most significant are indicated in figure 3, along with the sectors likely to be most seriously affected.

Figure 3. Socio-economic impacts of climate change in coastal zones

	More frequent floods	Erosion of coast	Inundation by sea water	Rise in water table	Intrusion of salt water	Changes in biological processes
Water resources			✓	✓	✓	✓
Agriculture	✓		✓	✓	✓	
Human health	✓		✓			✓
Fisheries	✓	✓	✓		✓	✓
Tourism	✓	✓	✓			✓
Human settlements	✓	✓	✓	✓		

The effects will not, however, be uniform. Certain coastal environments will be at greater risk, such as tidal deltas and low-lying coastal plains, for example, sandy beaches and barrier islands, coastal wetlands, estuaries and lagoons, and coral reefs and atolls. On this basis, increased coastal flooding is expected to be most severe in South and South-East Asia, Africa, the southern Mediterranean coasts, the Caribbean and in most islands in the Indian and Pacific Oceans.

The first step in designing strategies for adaptation is to collect information. Fortunately there are now multiple methods of data collection, including many types of equipment, from tidal gauges to satellite remote sensors, whose output can be combined with human experience gathered through questionnaires and other surveys. There are also many more ways of analysing and presenting this data using sophisticated computer graphics programs known as geographic information systems (GIS) that combine data from numerous sources and present them as maps. One simple application of GIS for coastal areas is to overlay scenarios of sea level rise on land elevations and the extent of development in different areas to highlight the likely impact zones – visual presentations that are valuable both for creating awareness and for planning responses.

Faced with the effects of climate change, communities in coastal zones have a choice of three basic adaptation strategies: protect, retreat or accommodate. Protection could mean building dykes; retreating could mean relocating homes or businesses, or demarcating certain zones as off-limits for development; accommodating could involve establishing stronger building codes, or strengthening early warning systems. A selection of the options is shown in figure 4.

Figure 4. Technologies for adaptation in coastal zones

Protect	Retreat	Accommodate
• *Hard structures* – dykes, sea-walls, tidal barriers, detached breakwaters • *Soft structures* – dune or wetland restoration or creation, beach nourishment • Indigenous options walls of wood, stone or coconut leaf, afforestation	• Establishing set-back zones • Relocating threatened buildings • Phasing out development in exposed areas • Creating upland buffers • Rolling easements	• Early warning and evacuation systems • Hazard insurance • New agricultural practices, such as using salt-resistant crops • New building codes • Improved drainage • Desalination systems

For **protection,** the most visibly reassuring option may be to build hard structures such as sea-walls. But apart from being very expensive these can have damaging side effects, for example by displacing erosion and sedimentation. It may be better therefore to consider soft options that involve restoring dunes or creating or restoring coastal wetlands, or continuing with indigenous approaches such as afforestation.

For **retreat,** the simplest approach might be to establish a set-back zone requiring development to be at a specified distance from the water's edge. And there are also intermediate options in the form of "easements" – legal agreements that restrict the size or density of structures within areas at risk and specify permitted types of shoreline stabilization. The area to which these apply can also be designed to automatically move or "roll" landward as the sea advances.

For **accommodation**, there is a variety of options. These will include warning systems for extreme weather events, as well as longer-term measures such as new building codes, or improving drainage systems by increasing pump capacity or using wider pipes.

Action for adaptation can involve many organizations or institutions, but in practice the responsibility tends to fall on the public sector. In coastal zones climate change is likely to affect food and water security, biodiversity, and human health and safety – collective goods and systems for which governments have prime responsibility. Nevertheless, at all stages governments should ensure continuous public consultation. This is mainly because people have a right to participate in the decisions that affect their lives, indeed they will demand it – communities all over the world are becoming increasingly resistant to top-down planning. But local acceptance and cooperation is also vital because most measures will depend on local expertise for implementation and maintenance. And there may be opportunities for more autonomous action by communities, as in Viti Levu, Fiji, where villagers have been actively involved in mangrove rehabilitation.

In some cases the private sector may also have an incentive to invest, as would be the case for combating beach erosion at tourist resorts. The private sector could also play a stronger role in transferring technology, given appropriate incentives in the form of investment subsidies or tax relief. And transnational corporations can help develop capacity in the host country if they are required to involve a local partner company.

There are also opportunities for non-governmental organizations. In addition to raising public awareness, they can act as intermediaries – identifying technologies, facilitating investment and providing management, technical and other assistance.

National action can be complemented with international support. Many governments in the least developed countries lack the capacity or the resources for many forms of adaptation, and have to rely on overseas development assistance. So far donors have been more supportive of mitigation, though nowadays as they come to appreciate its importance they are allocating more funds to adaptation.

Clearly, technology is not a panacea for dealing with the impact of climate change on coastal zones. Vulnerability also depends on prevailing social, economic and environmental conditions and existing management practices. Technologies for adaptation should, however, form a vital part of broader frameworks of integrated coastal management.

Box 1. Early warning systems in Bangladesh

Every year millions of people in coastal areas of Bangladesh are exposed to flooding. While much of this is beneficial, indeed essential, for agriculture, in some years it can be on a catastrophic scale, resulting in epidemics and in thousands of deaths as well as causing serious damage to habitats, agricultural production, fisheries and livestock.

Bangladesh has therefore been developing more effective early warning systems. Among these is a five-year project, the Community Flood Information System (CFIS), which is funded by United States Agency for International Development (USAID) and operated by the United States company Riverside Technology in partnership with two Bangladeshi institutions: the Center for Environmental and Geographic Information Services, and the Bangladesh Disaster Preparedness Centre.

Experience has shown that those best placed to prepare for and respond to disasters are local people. Prior to the project, most people obtained flood forecast information from a combination of sources: word of mouth, traditional knowledge and local media. But the first two are often inefficient and hit-or-miss, whereas local media reports can be difficult for people to understand.

The CFIS is designed to help Bangladeshi communities to adapt to the risks of floods and cyclones through a system of flood monitoring and forecasting and has already shown that timely flood warnings can prompt communities to protect crops, habitats and livestock. The Government of Bangladesh has recommended that the model be replicated in other flood prone areas.

Box 2. Restoring coral reefs with biorock

Rises in sea water temperature can damage coral reefs. One high-tech option for restoring reefs currently being tested involves making "biorock". This is created by passing a low-voltage electrical current through seawater, causing dissolved minerals to precipitate on to surfaces that eventually grow into white limestone structures similar to the materials that make up coral reefs and nourish tropical white sand beaches.

Biorock has been shown to accelerate coral growth in areas subjected to environmental stresses and help form structures that have been populated by a range of coral reef organisms, such as fish, crabs, clams, octopuses, lobsters, sea urchins and barnacles. More information on this technology is available at (www.globalcoral.org).

Water resources

All life – human, animal and plant – relies on sufficient and dependable supplies of water. But this vital resource is under pressure. Large urban populations, extensive irrigated agriculture and rapid industrial development are in many places using water faster than it can be replaced.

In response, policymakers are now taking a broader and more inclusive approach to water, referred to as integrated water resource management (IWRM). This is based on an understanding that the world's complex hydrological cycles depend critically upon healthy ecosystems and that the fresh water they deliver is a replicable but finite resource. IWRM also recognizes that water has both human and economic value – but that human requirements should take precedence. Essential water supplies should be accessible to all, and their distribution should be managed in a participatory fashion with a particular concern for the interests of the poor.

Climate change adds extra dimensions to this picture on both the supply and the demand side. On the supply side there are likely to be changes in precipitation patterns, with major implications for issues such as flood protection, food production, water-based transportation and many other forms of water-based livelihoods. On the demand side global warming will increase people's need for water and speed up evaporation from the surface of plants and from water sources such as ponds and lakes.

As with other outcomes of climate change, the water effects will vary considerably around the world. They are, however, likely to impinge most on the 40 per cent of the world's land area that is already under extreme climatic and hydrological stress – and they will be felt most by the poorest people who have the least capacity to adapt.

Although IWRM was originally conceived as a way of ensuring that water supplies are sustainable, it also provides a valuable and flexible framework for adapting them to climate change. In particular it highlights the opportunities for involving poor communities, and particularly women, who are in the best position to choose forms of water-supply adaptation that can safeguard the ecosystems on which they depend for cropping, livestock, fisheries and forestry.

IWRM will not, however, be sufficient on its own. Water managers now need to infuse IWRM with adaptation. In many cases the necessary technologies will already be in use and broadly diffused across both developed and developing countries. But in other cases they will need to transfer technology either within or between countries. For this purpose IWRM can make use of international networks of professionals and "communities of practice". These include the Global Water Partnership (GWP) – a group of government agencies, public institutions, private companies and multilateral development agencies that are committed to supporting countries in the sustainable management of their water resources. Among other things, GWP maintains the ToolBox for IWRM, an online resource for all sectors of water use. Other networks, such as the Soil and Water Research Management Network (SWMNet), have also been established at a regional level (see box 3) and these and other institutions, including the World Meteorological Organization, also maintain valuable databases on such issues as river flows.

In the past, when planning water supplies and distribution, managers and users have relied heavily on historical experience. With the extra uncertainty introduced by climate change, however, they will be working in a less predictable environment, and will need to consider not just one outcome but a range of possible scenarios for which they will have to compare and rank alternatives in terms of risks, costs and benefits.

Examples of the technology options they can build into these scenarios are listed in figure 5. Some are concerned with boosting supplies – by building more reservoirs, for example, or harvesting rainwater for agricultural use. Others involve reducing demand by cutting leakage from pipes, say, or switching from flush toilets to dry forms of sanitation. They can also be classified as hard technologies that involve new constructions or different types of equipment, or soft technologies that are more concerned with management of behaviour; thus, agricultural policy makers will consider both the hard option of encouraging more efficient types of irrigation as well as the soft option of introducing or modifying forms of water pricing.

Figure 5. Examples of adaptation technologies for water supplies

<table>
<tr><th colspan="2">Use category</th><th>Supply side</th><th>Demand side</th></tr>
<tr><td colspan="2">Municipal or domestic</td><td>• Increase reservoir capacity
• Desalinate
• Make inter-basin transfers</td><td>• Use “grey” water
• Reduce leakage
• Use non-water-based sanitation
• Enforce water standards</td></tr>
<tr><td colspan="2">Industrial cooling</td><td>• Use lower-grade water</td><td>• Increase efficiency and recycling</td></tr>
<tr><td colspan="2">Hydropower</td><td>• Increase reservoir capacity</td><td>• Increase turbine efficiency</td></tr>
<tr><td colspan="2">Navigation</td><td>• Build weirs and locks</td><td>• Alter ship size and frequency of sailings</td></tr>
<tr><td colspan="2">Pollution control</td><td>• Enhance treatment works
• Reuse and reclaim materials</td><td>• Reduce effluent volumes
• Promote alternatives to chemicals</td></tr>
<tr><td colspan="2">Flood management</td><td>• Build reservoirs and levees
• Protect and restore wetlands</td><td>• Improve flood warnings
• Curb floodplain development</td></tr>
<tr><td rowspan="2">Agriculture</td><td>Rain-fed</td><td>• Improve soil conservation</td><td>• Use drought-tolerant crops</td></tr>
<tr><td>Irrigated</td><td>• Change tilling practices
• Harvest rainwater</td><td>• Increase irrigation efficiency
• Change irrigation water pricing</td></tr>
</table>

Another useful addition to the IWRM framework is the concept of “soft paths”. This focuses on water not as an end product but rather as a service, and underlines the importance of sustainability. Thus, rather than trying to transfer water from distant sources it aims to exploit local resources by harvesting rain or storm water, for example, and it makes more efforts to treat wastewater using “green infrastructure” such as sand filters and wetlands. This will also involve focusing more on what is termed “green water”. As opposed to “blue water”, which is the visible volume above and below the ground, green water is the precipitation that is absorbed by soil and plants and subsequently returned to the atmosphere through plant transpiration. Green water is an under-valued resource even though it represents more than two-thirds of precipitation.

As with other adaptation measures, those for water supplies will need careful monitoring. Given the complexity of the issues and the number of factors involved this can be very difficult, but one way of assessing progress is to aggregate a number of indicators – of household welfare and water availability – into a single water poverty index.

Despite the growing urgency of the problem only a few developing countries have started drawing up national adaptation programmes of action. Mauritania, for instance, has carried out a needs assessment which indicates the potential for drip irrigation systems, but also highlights the importance of building better hydrological monitoring systems and involving communities in the management of water resources. Guyana, too, has made an assessment that includes the need to manage demand through water tariffs while reducing contamination of supplies with better septic tank systems and improving storm water drainage.

Clearly many more countries now need to consider the climate change implications for water supplies and to examine the most promising technologies for adaptation.

Box 3. The Soil and Water Management Network (cont'd)

For generations, smallholder farmers in Eastern and Central Africa have used their accumulated knowledge and ingenuity to improve and maintain soil quality. In recent years, however, as growing populations have put pressure on scarce land, these time-old techniques are proving inadequate. As a result the soil has steadily deteriorated – a process exacerbated by alternating floods and droughts, which have further degraded the land and in some countries led to famines.

In response, scientists and institutions in the region have established the Soil and Water Research Management Network (SWMnet) which helps them share knowledge and technologies and also aims to enable farmers, communities and countries to adapt and cope with climate variability. In addition, the network tries to enhance investments in soil and water management, to improve productivity and to increase the competitiveness of agricultural enterprises.

Much of this involves technology transfer. Since many technologies developed in one area have failed elsewhere, SWMnet facilitates and supports research to establish how these technologies can successfully be translated to different conditions. As part of this process SWMnet tries to ensure intensive, systematic and detailed stocktaking of knowledge and experience at local, national and international levels and consults with a wide range of groups, from individual farmers to non-government organizations (NGOs) to private enterprises and international agricultural research institutes.

Introducing these ideas can be difficult. Many countries in the region have very weak capacity for agrometeorology, so neither individual farmers nor national policymakers can take much account of climate variability. And regional planning has yet to fully exploit opportunities for trade and commodity exchange across zones and countries. Nevertheless, SWMnet has fostered an active dialogue between practitioners and is supporting institutional development.

Box 4. Seasonal forecasting in Burkina Faso

In the Sudan-Sahel region agriculture is largely rain-fed, so rural households, most of which depend on farming, should in principle be able to increase their productivity if they have better weather forecasts. To test this proposition in Burkina Faso, the United States National Oceanic and Atmospheric Administration funded the Climate Forecasting for Agricultural Resources project, which began in 1997. A wide range of stakeholders including farmers, government agencies, provincial representatives of government ministries and other local stakeholders participated in the project along with an international NGO which provided support for logistics and communications.

In the first phase (1997–2001) the project studied local forecasting knowledge and farmers' information networks as well as their strategies for adapting to climate variability. The second phase (2001–2004) used radio broadcasts and workshops to disseminate seasonal rainfall forecasts, while monitoring farmers' and pastoralists' responses.

These forecasts had their limitations. The information was presented as broad probabilities: the likelihood of rainfall being in the higher, middle, or lower percentile of the region's total historical seasonal rainfall. And apart from often being late the forecasts were only of total rainfall for the season, rather than of its likely distribution by day or by month; nor were they for specific farm locations.

Nevertheless, the project did show that most rural producers, even those with limited resources, could benefit from climate forecasts by making small adjustments in their livelihood and production strategies. Clearly, however, if they are to do so more effectively farmers will need more precise forecasts and greater support in interpreting them.

Just as important, the Government will need to be convinced of the financial and political viability. When the project was completed the Government of Burkina Faso not only lacked the resources to continue with these activities, it also feared the potential political consequences of forecast failure.

Agriculture

Minor climatic variations can have a major impact on agricultural output even in a single growing season, so long-term agricultural productivity and food security will certainly be affected by ongoing climate change – a matter of increasing concern since over the next 30 years global food production will need to double to feed the planet's growing population.

In its *Third Assessment Report the Intergovernmental Panel on Climate Change* presented a number of scenarios and looked at the implications for global regions. For Africa it concluded that many countries would experience a fall in grain yields and would be vulnerable to droughts, floods and other extreme events that would put greater stress on water resources, food security and human health. For Asia it concluded that many countries – in arid, tropical and temperate zones – could see food security undermined by thermal and water stress, sea level rise, floods and droughts and tropical cyclones. And for Latin America it envisaged falling yields of important food crops and in particular a risk for subsistence farming. At higher latitudes agriculture is expected to benefit from climate change as a result of longer growing seasons and increased warmth – but technologies would also be needed to take advantage of these opportunities.

To some extent, plants can cope with climatic extremes on their own. Some have a natural adaptive capacity, such as certain rice cultivars that flower early in the morning, enabling them to avoid the damaging effects of higher temperatures later in the day. However, relatively little is known about the general potential for plant resistance to high-temperature stress and studies have been few and inconclusive.

Most of the adaptation for crop production is likely to rely on human intervention. Fortunately, farming communities have considerable experience of coping with adverse climatic events, such as droughts and, floods, and with salinity. They have, for example, introduced new forms of irrigation, or diversified to varieties that are higher yielding or have greater tolerance for drought or salty conditions. They have also changed land topographies by using "grass waterways" – areas where grass is left to grow permanently to drain run-off water. Some of the available options are listed in figure 6.

Figure 6. Examples of adaptation options for agriculture

Response strategy	Some adaptation options
• Use different crops	• Carry out research on new varieties
• Change land topography to improve water uptake and reduce wind erosion	• Subdivide large fields • Maintain grass waterways • Roughen the land surface • Build windbreaks
• Improve water use and availability and control erosion	• Line canals with plastic films • Where possible, use brackish water • Concentrate irrigation in periods of peak growth • Use drip irrigation
• Change farming practices to conserve soil moisture and nutrients, reduce run-off and control soil erosion	• Mulch stubble and straw • Rotate crops • Avoid monocropping • Use lower planting densities
• Change the timing of farm operations	• Advance sowing dates to offset moisture stress during warm periods

On the whole, agricultural systems are fairly flexible so if farmers have access to the right information and tools they should be able to make many of the necessary adaptations on their own. But some will find it more difficult, because of poor soil quality, perhaps, or inadequate water supplies or the lack of funds for investment. In addition they may face institutional or cultural barriers. In these cases governments may want to help through more deliberate and planned interventions, by offering new knowledge or equipment or seeking new technologies.

Fortunately, research, development and technology transfer in the agriculture sector can benefit from existing global networks. One of the most important is the Consultative Group on International Agricultural Research (CGIAR) – a strategic alliance of international organizations and private foundations that works with national agricultural research systems and civil society organizations as well as the private sector. Any country can link its own research efforts to this global system.

One of the main focuses of international research for adaptation to climate change will be the search for a new generation of crop varieties. Much of the increase in yields in recent decades resulted from improved management practices, irrigation and increased use of fertilizers or other inputs, but around half was due to genetic improvements in crop varieties.

Many of these advances have resulted from technology transfer. Because crop varieties are sensitive to local conditions, much of this has therefore been between regions with similar agroclimatic conditions. Thus there have been North-North transfers between temperate regions and South-South transfer across tropical or subtropical regions. The potential for South-South transfers was exploited during the Green Revolution when semi-dwarf wheat varieties originally developed in Mexico were transferred to India, which also benefited from infusions of germ plasm collected by the International Rice Research Institute from other parts of Asia.

Many of the hybrids currently used are the products of traditional forms of cross-breeding. In future, however, some of the greatest potential will lie with more advanced forms of biotechnology. One concern, however, is that if the results are to be made freely available there will be less investment in research. If individual nations do not capture the full gains from improved crop yields they may choose to invest less.

Indeed, national research institutes are generally underfunded. The alternative is to rely more on the private sector, but here the "free-rider" problem is even more acute. Naturally occurring plants are not considered patentable inventions and so there will be little incentive for companies to preserve and protect genetic resources and to screen them for their potential usefulness. This has led to greater efforts to apply international property rights to biological inventions, and breeders have often deliberately produced new varieties that either do not reproduce or whose progeny have substantially lower yields. With this type of incentive, private plant breeding research has expanded greatly; in the United States, for instance, activity more than quadrupled between 1970 and 1990.

Nevertheless, it is important that the benefits of research are widely shared. The CGIAR's programme, for example, combines modern and traditional methods of genetic crop improvement, and includes the interests of all stakeholders, including farmers, local communities, breeders and biotechnology companies.

Even if new technologies are devised, and are suitable for local conditions, it can be difficult for the poorer farmers to adopt them. With small farm sizes and limited access to credit, they may have neither the ability nor the inclination to invest in new technology.

A warmer world with an expanding population will have to grow considerably more food. Adaptation will thus be vital not just for the livelihoods of farming households but also for global food security – an indication of the need for much more research and for international cooperation in developing the necessary technologies.

Box 5. Floating agriculture in Bangladesh

Farmers in Bangladesh who live in areas that remain inundated for long periods every year have traditionally used *vasoman chash,* or floating agriculture – a system similar to hydroponics, in which plants derive their nutrients not from soil but from water. And compared with traditional land-based gardens the floating beds, which are mostly used to cultivate vegetables, are more fertile and more productive.

To make the beds, the farmers prepare "bio-land" which comprises water hyacinth, aquatic algae, waterwort or other waterborne creepers, along with straws and herbs or plant residues. A typical bed might be 50 metres long by 15 metres wide and about three quarters of a metre high – though the size, shape and materials are adjusted according to local circumstances to ensure that the bed can cope with the monsoon and tidal floods. After the harvest, the farmers also preserve the stubble for the preparation of subsequent beds.

As a result of climate change, the south-western and coastal areas of Bangladesh will become more vulnerable to inundation. To help coastal communities adapt to these effects the floating bed option has been promoted through a number of projects, including Reducing Vulnerability to Climate Change and the Sustainable Environment Management Programme.

Since this technology is already well adapted to local circumstances, there are few barriers to extending it elsewhere in the country, though some areas may lack sufficient water hyacinth and other aquatic vegetation. Some of the more marginal farmers may also need small amounts of financial capital.

Box 6. Mexican farmers learn new irrigation methods

Farmers in Sosa, Oaxaca Valley, Mexico, had been over-extracting groundwater and using it inefficiently and this, combined with drought, had caused water sources to be depleted. The farmers initially wanted to respond by digging more wells, but Mexico's National Water Commission turned down their request for support.

The farmers turned instead to a bilateral donor agency which suggested they take a different approach. This has involved introducing new and more efficient methods of irrigation, and learning how to produce organic vegetables and other crops. Now the farmers have a new irrigation system housed in a 1.5-hectare greenhouse that is fitted with an automated system with sprinklers and drip lines to supply the soil with water and nutrients, both inside and outside the complex.

A local groundwater technical committee was formed to organize the project and explain to farmers the causes and effects of watershed depletion and how to adopt the new technologies. The National Water Commission met half the cost while local governments financed 25 per cent and the farmers contributed the rest. Of the 88 families in Sosa, 80 now use the new technology, and they are planning to expand by increasing the size of the greenhouse.

Meanwhile, the National Water Commission has reported that the groundwater in the Oaxaca Valley is returning to healthy levels. With climate change threatening to increase the frequency and severity of droughts, these more efficient forms of irrigation can help small farmers sustain their livelihoods.

Public health

Many aspects of human health are affected directly or indirectly by weather and climate. The impact may be direct – high temperatures causing heatstroke, say, or floods or landslides leading to death and injury. Or it can be more indirect – as environmental changes accelerate the transmission of infectious diseases, or water shortages undermine systems of hygiene or reduce crop yields, leading to malnutrition.

On the other hand, climate change may in some places bring about health improvements if, say, they result in a less hospitable environment for specific disease vectors or pathogens. Similarly, for cardiovascular and respiratory diseases, higher temperatures might cause a small increase in mortality in tropical countries but reduce the number of deaths in temperate regions.

Some of these effects are listed in figure 7. It should be emphasized, however, that the chain of cause-and-effect is often extremely complex and the actual health outcomes of climate change will depend on many other factors such as the distribution of wealth and income, the condition of the public health infrastructure and access to adequate nutrition, safe water and effective sanitation.

Figure 7. Some health effects of weather and climate

Event	Some potential damaging health effects
• Warmer climate	• Can create conditions for the spread of new vectors such as those for malaria, dengue, tick-borne encephalitis, and Lyme disease. • Higher temperatures shorten the development time of pathogens
• Drought	• Less water for hygiene • Reduced food supplies cause malnutrition • Forest fires reduce air quality
• Heatwaves	• Heatstroke and increases in mortality from cardiovascular and respiratory diseases
• Floods, landslides and windstorms	• Deaths and injuries • Disruptions to water-supply and sanitation systems and health-care infrastructure. • Post-traumatic stress disorders • New breeding sites for mosquitoes

Taking these into account, the IPCC has concluded that climate change is likely to undermine health mainly within tropical and subtropical countries and predominantly in lower-income populations. The World Health Organization too has considered the effects and has estimated that, in 2000, climate change caused.

In the developing countries, millions of people already live in unhealthy conditions with poor access to health care. Here most the damaging effects are likely to be through diarrhoeal disease and malnutrition. Developing countries may also see a rise in malaria – this may not make much difference in areas where the disease is already highly endemic, but could lead to increased exposure in some countries where the disease is not yet widespread.

Developed countries should be in a stronger position. Generally they can base adaptation strategies on current public health measures, while augmenting or improving them to address heightened threats. For example, higher ambient temperatures will favour the growth and spread of the food-borne disease, salmonella, so in a warmer world even developed countries may need to enhance current programmes – and especially to encourage proper food handling. Developed countries may also need new programmes to combat diseases such as malaria that may have been close to its boundary conditions and could spread more rapidly in a warmer climate. And even wealthy countries can have pockets of poverty and populations at risk whom they will need to protect during extreme climatic events, as demonstrated by the heatwave across Europe in 2003.

As with public health measures generally, those designed to address the risks from climate change will operate at various levels, from the individual to the community to the country. To cope with higher temperatures, for example, individuals will need information on appropriate responses, including higher intake of fluid. And at the community level, local authorities can provide cooling centres to which vulnerable people can resort on particularly hot days. At the national level, governments can in the short term improve weather forecasting, and for the longer term introduce regulations to ensure that climate change projections are taken into account when designing new buildings.

Measures for adaptation can be classified as legislative, technical, educational or behavioural. In the case of waterborne diseases governments may legislate to raise standards of water quality, and improving treatment of drinking water. But they can also advise communities to boil water as appropriate and encourage individuals to wash their hands more frequently. These and similar options are illustrated in figure 8.

Figure 8. Examples of adaptation options for health

Health issues	Legislative options	Technical options	Educational and advisory	Cultural and behavioural
• Extreme weather events including thermal stress	• New planning laws • New building guidelines	• Urban planning to reduce heat island effects • Air conditioning	• Early warning systems	• Using appropriate clothing • Taking siestas in warm climates • Using storm shelters
• Air quality	• Emission controls • Traffic restrictions	• Improved public transport • Catalytic converters • Tall chimneys	• Pollution warnings	• Carpooling
• Vector-borne diseases		• Vector control • Vaccination, impregnated bednets	• Health education	• Greater care with water storage

Figure 8. (cont'd)

Health issues	Legislative options	Technical options	Educational and advisory	Cultural and behavioural
• Waterborne diseases	• Watershed protection laws • Water quality regulation	• Genetic/ molecular screening of pathogens • Improved water treatment and sanitation	• Boil water alerts	• Washing hands and other hygiene behaviour • Using pit latrines

Many of the measures designed for adaptation can also be beneficial for mitigation, and vice versa. Thus, in urban areas communities can take adaptive measures to reduce the "heat island" effect by planting roof gardens, which also provide insulation and therefore reduce energy requirements and the need to burn fossil fuels. Similarly, mitigation measures in transport to reduce vehicle emissions will also have benefits for health by improving air quality.

To counter the health impact of high temperatures and of extreme weather events one of the most valuable tools is an effective early warning system. One example is that developed for the El Niño of 1997–98. Researchers had alerted governments in the Pacific of likely changes in rainfall and storm patterns, with the potential for severe droughts and unusually high risks of typhoons and hurricanes. As a result governments carried out public education and awareness campaigns to reduce the risk of waterborne and vector-borne diseases. In many cases this proved very effective; in Phonpei, Micronesia, for example, despite the water shortage the number of children admitted to hospital with severe diarrhoeal disease was actually lower than normal.

Climate-based early warning systems can also be created for a number of diseases, including cholera, malaria, meningococcal meningitis, dengue, African trypanosomiasis, yellow fever, Rift Valley fever, leishmaniasis, West Nile virus, Ross River virus and various forms of encephalitis. These and other warning systems will depend, however, on effective systems of surveillance and disease control.

There is thus a wide range of potential interventions to counter the health impacts of climate change, but these can face serious obstacles. The most general barrier is poverty. Governments in developing countries are typically operating under such financial constraints that they may be unable to carry out some basic public health measures and may lack the necessary equipment, such as sufficient refrigerators to maintain a cold chain for vaccines, or aeroplanes to extinguish forest fires. Individuals and communities maybe unable to act on advice because they are too poor; during a cholera epidemic in Brazil, for example, people were advised to filter water or collect rainwater but often could not afford simple filters or tanks. Another issue can be ignorance of the links between the environment and human health; some traditional communities may thus fail to take essential steps to protect themselves.

The associations between weather, climate and human health also require much more research. It would be helpful to gather the necessary meteorological, environmental and socio-economic data at appropriate scales to be able to map likely hazard and identify the communities who are especially vulnerable.

Box 7. Early warning systems for heat events

Extreme heat can be very dangerous, especially if communities have not been warned or taken the necessary precautions. And the situation is likely to become even more critical in future as a result of rapid urbanization, ageing populations and the prospect of heat events that are more frequent, more intense and longer lasting.

One example of an effective response plan is the Philadelphia Hot Weather Health Watch/Warning System in the United States of America. This has many components, including:

- Media alerts – TV, radio and the press publicize heat events, explaining how to avoid heat related illnesses and encouraging friends, relatives, neighbours and others to make daily visits to the most vulnerable.
- A 'Heatline' – the public can call the Heatline for information and counselling on avoiding heat stress.
- Targeting high risk institutions – the Department of Health offers advice to nursing homes and other facilities with vulnerable residents.
- Utility policies – during warning periods, the local utility company and water department halt any planned service suspensions.
- Emergency services alert – during warnings, the Fire Department Emergency Medical Service increases its staffing.
- Help for the homeless – the agency for the homeless conducts increased daytime outreach activities to assist those on the streets.
- Facilities for cooling – senior citizen centres that have air-conditioned facilities extend their hours of operation.

Even in the United States of America, however, many cities lack such thorough preparations. One survey of cities vulnerable to heat events found that one third lacked any written heat event planning, and that of the ten cities with plans, one third of these were no more than cursory.

Infrastructure

All human settlements are critically dependant on many types of infrastructure, from power and water supplies to transportation to systems of waste disposal. In many parts of the world, particularly in developing countries, this infrastructure is already under severe strain, as a result of population growth, rural–urban migration, high levels of poverty and the demand for more roads and vehicles. All these strains are likely to interact with, and be exacerbated by, different aspects of climate change.

Some of these effects will be direct. Changes in temperature or rainfall along with sea level rise or extreme weather events will have an immediate impact, as storms or hurricanes bring down power lines, wash away roads or bridges or overwhelm systems of drainage. There can also be less obvious, longer-term changes; if higher temperatures lead to drier soils, for example, this could lead to subsidence.

Most governments have the appropriate legislation and administrative systems to ensure that the infrastructure can resist typical climate or weather related events. As a result these considerations are often incorporated into the wide range of environmental assessments that are now common for urban settlements – environmental impact assessments, capacity studies, environmental audit procedures, state of the environment reports, statutory plan consultations and participatory planning procedures. In some cases, urban settlements have also used a combination of assessments to develop "Local Agenda 21s". Manizales in Colombia provides an excellent example of a long-term community-based environmental plan (box 8).

Adaptation strategies will thus largely be based on existing experience – ensuring that current requirements are enacted and, where necessary, strengthened to meet the future challenges of climate change – and required good information. For simple hazard mapping, authorities largely use accumulated experience. In future, however, they will have to make more use of vulnerability-based assessments, which will require accurate and comprehensive data on land use, for example, and the location of infrastructure which can then be fed into computer simulations through GIS. But rather than trying to predict extreme climatic events precisely, such assessments can also incorporate more probabilistic and uncertain information to help planners consider the broader context of the problem and suggest a range of responses.

Box 8. Local Agenda 21s and urban environmental management

The city of Manizales in Colombia is in a region of high seismic and geological risks which could be heightened by climate change. Many of the road systems are inappropriate to the settlement's topography and could be damaged by landslides or flooding. Dwellings are often in dangerous locations. In addition many industries have been contaminating rivers, lakes, wetlands and coastal zones.

In 1990 the city started to prepare a local environmental action plan as a means of implementing Agenda 21. Then, following national decentralization policies, it consolidated local environmental management and the city authorities started to cooperate closely with the Autonomous University of Manizales, which sought to make Manizales a pilot project for all of Colombia.

On of the main aims of this project has been to improve the capacity for local participation. In one case the university, residents, and ecological and environmental non-governmental organization groups joined in a citizens' forum and were able to formalize an agreement for a local environmental action plan.

The university also collected a range of data to form the basis for monitoring conditions and trends and has established a system of urban environmental observatories, where the community has access to environmental information and programmes of environmental education.

The Manizales project, some of which has been financed by new property taxes, has helped to resolve some of the environmental problems in the poorest communities and has helped to establish three mixed economy enterprises: solid waste dumps, a recycling plant and a centre for supplies.

By their nature, urban areas are constantly changing and have myriad and shifting interconnections. To deal with these complex and dynamic systems, planning authorities have devised a number of programmes and approaches. One is the "smart growth" method, which indicates how authorities can combine a number of planning practices to encourage more sustainable patterns of growth (box 9).

Some of the main technologies, hard and soft, for adaptation in infrastructure are summarized in figure 9. Within the building sector this includes zoning to move developments away from areas that could be more prone to flooding, while seeking opportunities to make cities more energy efficient using combined heat and power systems and making greater use of trees to moderate the heat island effects.

Figure 9. Examples of infrastructure technologies for adaptation

Hard technologies	Soft technologies
Building sector	
• Lay out cities to improve the efficiency of combined heat and power systems and optimize the use of solar energy • Minimize paved surfaces and plant trees to moderate the urban heat island effects and reduce the energy required for air conditioning	• Limit developments on flood plains or potential mud-slide zones • Establish appropriate building codes and standards • Provide low-income groups with access to property
Transportation sector	
• Cluster homes, jobs and stores • Control vehicle ownership through fiscal measures such as import duties and road taxes as well as through quotas for vehicles and electronic road pricing • Develop urban rail systems	• Promote mass public transportation • Use a comprehensive and integrated system of planning • Link urban transport to land-use patterns
Industrial sector	
• Use physical barriers to protect industrial installations from flooding	• Reduce industrial dependence on scarce resources • Site industrial systems away from vulnerable areas

Governments may also need to change building codes while providing the housing and commercial building sectors with appropriate information and education through industry training schemes. They may also need to support the construction industry through programmes of research, development and demonstration. At the same time, for these measures to be effective governments will also need to strengthen the capacity of local authorities and of the agencies responsible for enforcement.

Householders too will need to become aware of such issues, especially in poorer communities where they are more likely to be building or maintaining their own homes. For this purpose, authorities could, for example, prepare home-owner guides. Nevertheless, even when they are aware of what needs to be done many households will be unable to afford the immediate investments that they know would bring long-term gains.

The transport sector presents a particular challenge, given the dependence on petroleum-based fuels, prevailing individual transport modes and well-established travel lifestyles. But a number of cities have shown what is possible. Singapore, for instance, has been adapting to the growth of urban transport using a number of measures that will be also relevant for additional pressures resulting from climate change. This includes developing better systems of mass transportation, and trying to reduce the need for travel by creating urban zones that cluster homes, shops and workplaces together.

For industry, many of the adaptations to climate change will be linked to location. Industries will need to be sited away from vulnerable areas such as coastlines where sea level rise will result in inundation. Other measures will be directly related to their use of inputs; so enterprises will want to reduce their dependence on large amounts of water or they could become vulnerable to fluctuations in supply. Others may in the future have to respond to the more indirect effects of climate change: Food manufacturers, for example, may find themselves adjusting to a shortage of agricultural inputs or changing patterns of consumer behaviour.

Adaptation for infrastructure will thus demand many types of change, in both the public and private sectors. In general the most successful strategies are likely to be those where the proposals for adaptation meet a number of human needs beyond environmental benefits.

Box 9. Smart Growth planning networks

Currently 32 organizations around the world have come together to form a network that encourages development based on "smart growth". This is a decision-making framework guided by the following ten principles:

1. Encourage mixed land use;
2. Take advantage of compact building design;
3. Create a range of housing opportunities and choices;
4. Create walkable neighbourhoods;
5. Foster distinctive, attractive communities with a strong sense of identity;
6. Preserve open space, farmland, natural beauty and critical environmental areas;
7. Strengthen and direct development towards existing communities;
8. Provide a variety of transport choices;
9. Make development decisions predictable, fair and cost effective;
10. Encourage community and stakeholder collaboration in development decisions.

Of the ten principles, the final one is particularly important; stakeholders need to be brought into the decision-making process early on. This could be achieved, for example, by enabling local government officials and residents to visit ongoing smart growth communities and by taking care to illustrate complex concepts with photographs and imagery.

It is also important to emphasize how smart growth projects can be profitable. This will encourage support from investors, lenders, developers and entrepreneurs. And in order to convey a stable and predictable development process local governments must act uniformly and consistently.

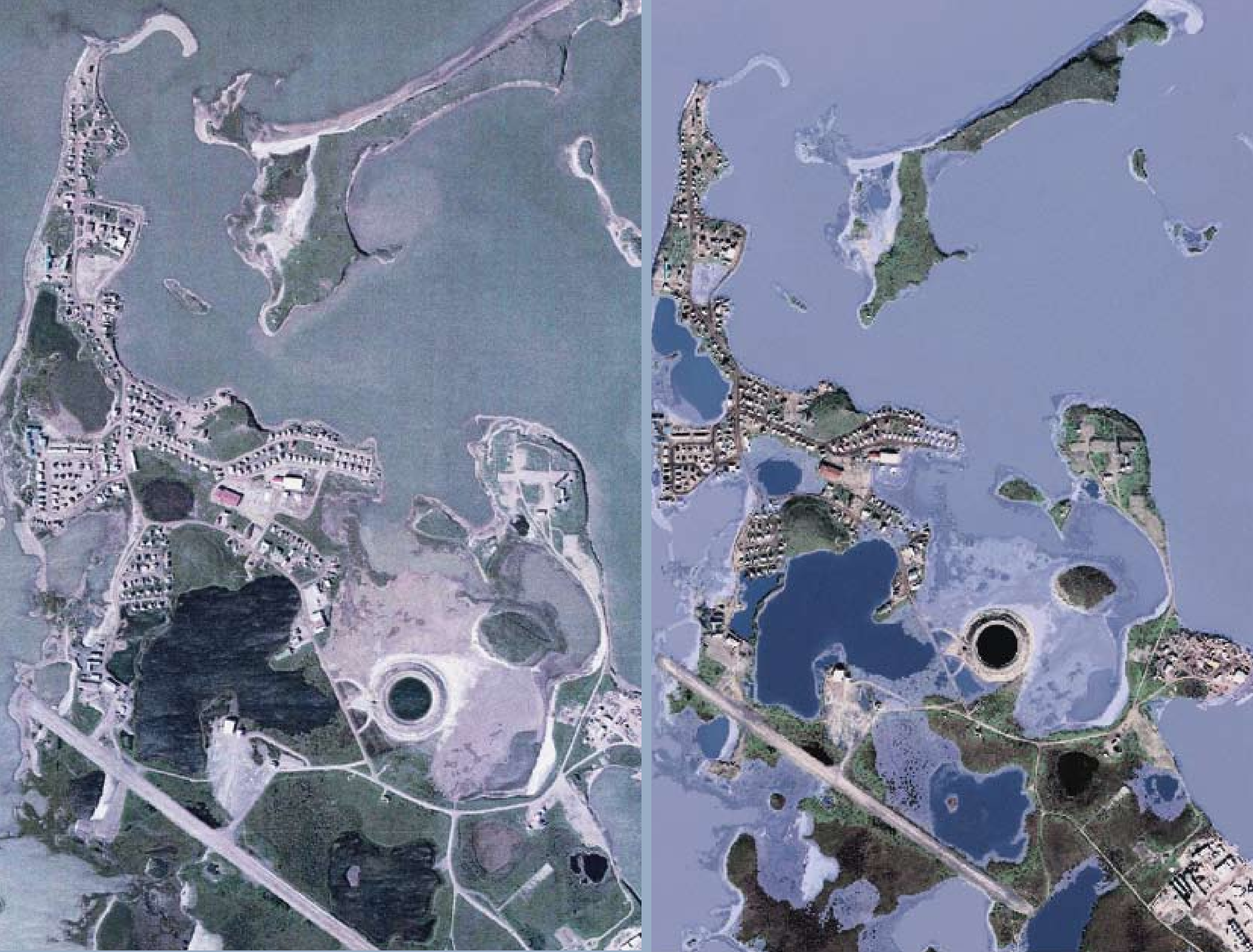
Action for adaptation

Climate change is causing the earth's surface temperature to rise and increasing the prospect of extreme weather events that will be more frequent and intense. To some degree this will affect everyone, though for a specific location it is difficult to predict how and when such changes will take place. What is certain is that people living in fragile and difficult ecosystems, or in poorer areas of many of the world's rapidly expanding cities, will become even more vulnerable, with risks to their health, their well-being and their livelihoods. Nevertheless, as this brief summary has indicated, it may be possible to adjust to most of these changes and to protect those most at risk.

Fortunately, the world already has considerable experience of many types of adaptation and knowledge that can fruitfully be shared both within and between countries. The most general lesson is that many of the measures required are essentially social and political – people living in poor housing conditions, or trying to eke out a living from small plots of land with poor soil and little water, have always suffered most from climatic extremes. The remedies for this may be difficult or contentious but technologically they are relatively straightforward.

Even where adaptation requires the application of technology, some of the methods can be fairly basic, often using measures that would have seemed familiar to people living decades or even hundreds of years ago. Others, however, can employ much higher levels of technology, from advanced plant genetics to computer-controlled flood barrages, while some prospective technologies appear to come from the fringes of science fiction.

Whatever the envisaged levels of technology, it is clear that all countries now need to devise national strategies for adaptation, assessing the communities and the locations at greatest risk and planning appropriately. This is becoming increasingly urgent since the quality of today's decision-making on agricultural or industrial development or on the layout of towns and cities could all too soon be tested against future variations in climate. The scientific warnings may not yet provide the level of precision desired by many planners, but they portray with certainty a rapidly warming world with consequences that globally, and for most people, are largely negative. A new climate is on the way. Adaptation is not a choice, it is a necessity.



Light Detection and Ranging (LiDAR) technology can be used to create highly accurate digital elevation models of the coastal zone. Here, LiDAR elevation data are used to model the extent of flooding in Tuktoyaktuk, North West Territories, Canada, as a result of a 2.20 m storm surge combined with a projected rise in sea level of 0.30 m for 2050.